Simulations of ITER and ITER-like Discharges in Alcator C-Mod

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Utilizing experimental tokamaks to provide the basis for simulating ITER

• Simulations of ITER discharges are based on a series of physics models

• We use these simulations to project ITER discharge behavior to assist the design and operational planning

• How do we check that our simulations are reasonable
  – Establish ITER-like discharges on existing tokamaks (C-Mod, DIII-D, JET, and AUG are presently participating)
  – Simulate these discharges with the same tools and approaches used in simulating ITER, to the extent possible, and test their effectiveness
  – Test the physics models directly against experiments and compare these observations among the 4 tokamaks
Alcator C-Mod and the Tokamak Simulation Code (TSC)

C-Mod is a high field compact tokamak, the ITER-like discharges parameters:

- \( I_p = 1.3\text{--}1.35 \text{ MA} \)
- \( B_T = 5.4 \text{ T} \)
- \( R = 0.67 \text{ m} \)
- \( a = 0.22 \text{ m} \)
- \( \kappa = 1.75\text{--}1.85 \)
- \( q_{95} = 3.0 \)
- \( n/n_{Gr} \sim 0.5 \rightarrow 0.85 \)
- \( \beta_N \sim 1.0 \rightarrow 1.7 \)
- \( H_{98} \sim 0.65\text{--}0.9 \rightarrow 1.0 \)

TSC is a time-dependent 1.5D free-boundary axisymmetric plasma evolution code.

TORIC for ICRF analysis in TRANSP
Simulations of ITER indicate that volt-seconds can be saved by heating in the Ip rampup in L-mode.

C-Mod confirms that resistive V-s savings are preserved to the end of flattop.

Ohmic rampup case in C-Mod
ICRF heating in C-Mod rampup is 2 MW, with the plasma remaining in L-mode.

Ohmic rampup case in ITER
ICRF heating in ITER rampup is 5-20 MW, with the plasma remaining in L-mode.
Simulations of ITER indicate that heating in the Ip rampup can broaden the current profile, lower li

Ohmic rampup case in ITER consumes all available flux in rampup

ICRF heated rampup in ITER reduces OH coil current swing, and causes divertor coil to have higher current $\rightarrow$ lower li & lower flux state

Ohmic rampup case in ITER, li(1) reaches 1.35

ICRF heated rampup in ITER, li(1) reaches 1.15
Recent discharges: ICRF heating in the Ip rampup of C-Mod saves V-s with little or no change in li

ICRF heating during the Ip ramp is clearly saving volt-seconds over the ohmic rampup

There is nearly no difference between the current profiles in the rampup

Need to simulate these recent C-Mod discharges to resolve this

Ohmic (1090911006)
ICRF, 1 MW (1090911012)
ICRF, 2 MW (1090911026)
The electron temperature profile near the plasma edge determines the evolution of the j-profile, $li(t)$

The Coppi-Tang energy transport model is used in simulations of C-Mod discharges and ITER discharge projections, which is based on profile consistency and analytic drift wave theory.

In the model one can adjust the magnitude and shape of $\chi(\rho)$, which adjusts the resulting $T(\rho)$.

A broader $T_e(\rho)$ in L-mode is required to match the C-Mod experimental data, than is typically used for ITER simulations with this model.
The approaches used in ITER simulations are generally supported by simulating C-Mod expts

Multipliers used with Coppi-Tang model are applied in discharge regimes (L-mode, H-mode) similar to modeling ITER discharges, NOT microfit at every time slice

TORIC analysis to get power depositions into thermal species for C-Mod and ITER simulations

In C-Mod use only 2 density profiles, an L-mode and H-mode profile shape, with magnitude from expt’l data

On C-Mod we use total radiated power emissivity profiles and $Z_{\text{eff}}$ data to bypass direct modeling of impurities

For ITER we model impurities assuming they have the electron density shape and coronal equilibrium
The Ip rampdown in ITER is complex because there are several constraints and unknowns.

- Rampdown Ip, and maintain diverted plasma to very low Ip (down to 0.1xIp)
- Rampdown $\kappa$ (1.4-1.5) to avoid vertical instability as li rises (2.5-2.7)
- Terminate burn
- Avoid flux consumption
- Avoid OH coil over-current during H to L transition
- Maintain midplane coupling during heating yes, but….
- Maintain divertor strike points for particle and power handling not yet

What will the density evolution be?
What will the confinement regime be?
The H to L transition in ITER is a critical issue, examining H to L transitions in C-Mod Ip rampdown.

C-Mod shows the same over-current in its OH coil that the ITER central solenoid coil does when the plasma goes from H to L mode.

C-Mod indicates that the H-mode must be sustained sufficiently long into the rampdown, or the OH coil will have an over-current.

Ramping Ip down fast enough can mitigate an over-current in the OH coil.

Early H to L (1091006009)
Later H to L transition (1091006008)

Latest H to L (1091006025)
H to L transition with faster Ip rampdown (1080409016)
Results

Experiments on C-Mod are contributing to the understanding of ITER discharge behavior projections, and the demonstration of ITER-like plasmas is continuing.

C-Mod has observed that ICRF heating can save volt-seconds in the L-mode Ip rampup phase.

C-Mod has identified an “apparent” discrepancy between ITER projections and experiments, future work will determine if ICRF heating in the L-mode Ip rampup of ITER can broaden the current profile.

C-Mod has indicated that the electron temperature profile which matches experimental measurement is broader than the one used in ITER simulations, and this will be used for ITER to see the impact on li.

C-Mod has observed the OH coil over-current response to the H to L transition seen in ITER simulations, and indicated some directions for mitigating its effects.

C-Mod experiments can be modeled reasonably well with several of the same approaches used in ITER modeling.